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(54) **Wheel balancer two plane calibration apparatus and method.**

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Description

Background of the invention

1. Field of the invention

This invention relates to a system for measuring and displaying unbalance in a rotating body and more particularly to such a system which has the capability of measuring and providing correction quantities for system imposed unbalanced measurement errors.

2. Description of the prior art

U.S. Patent 4,285,240, Gold, issued August 25, 1981 discloses an off-the-car wheel unbalance measuring system having a rotationally driven wheel mounting shaft supported in a pedestal. A pair of force transducers are mounted in the pedestal adjacent to and spaced axially along the shaft. The force transducers are coupled mechanically to the shaft and provide periodic electrical output signals indicative of unblance forces transmitted through the shaft when the shaft is driven rotationally. The angular position of the shaft is monitored with respect to an angular reference position at a predetermined number of angular increments during each full revolution of the shaft. The transducer output signals are converted to digital form in electrical circuitry within the system and calculations are performed on the digitized signals at each angular increment using sine and cosine representative factors corresponding to the particular angular increment. The sine and cosine factors are stored in memory and are called up from storage in accordance with the monitored angular position of the shaft. This system operates to provide operating data from which unbalance force magnitude and angular position may be calculated. Operation of the system while a known unbalance is mounted on the shaft provides data from which calibration constants for the system may be calculated. The system may also be operated while the shaft is running free and data collected which is indicative of the unbalance in the shaft itself. These data may thereafter be used to provida error correction for operating data wherein the errors accrue from transducer idiosyncrasies and/or inherent shaft unbalance.

In GB—A—1 155 402 a method of calibrating an unbalance analyser of the type which can operate over a range of speeds of rotation of the assembly to be balanced is disclosed. In this prior art the unbalance analyser may include two vibration pick-ups for sensing vibrations in a first and a second correction plane respectively, and the method includes the steps of rotating an unbalanced assembly and sensing the unbalance in one of the planes with one of the pick-ups which produces a first unbalance signal, generating a first calibration signal which is such as to cancel out th first unbalance signal, and thereafter generating a second calibration signal which is such as to cancel out a second unbalance signal from the other vibration pick-up at the second correction plane, and thereafter completing the calibration by standard pr cedur .

The calibration is preferably completed by adding a known weight to the rotating assembly in a known position, rotating the assembly and sensing the unbalance in the first correction plane by means of the first vibration pick-up, producing a new unbalance signal therefrom, and adjusting the controls of the analyser so that the analyser indicates the correct amount and position of the added weight. This procedure is then repeated by sensing the unbalance in the second correction plane by means of the second vibration pick-up in order to take into account the calibration of the analyser for the second correction plane.

The calibration may also be completed by attaching a known unbalance weight to the rotor in one correction plane, e.g. the first correction plane. The analyser controls are then manipulated so that the first correction plane amount and position meters read the correct amount and positon of this unbalance. In the next step of the calibration procedure, the unbalance weight is removed and a known unbalance weight is attached to the rotor in the second correction plane. The proper analyser adjustment controls are then manipulated so that a second set of meters corresponding to the second correction plane read the proper amount of unbalance and the correct position of the unbalance.

Summary of the invention

The present invention provides an improved apparatus for calibrating a balancing machine for dynamically balancing objects rotatable on a shaft thereof, said apparatus comprising th means defined in claim 1.

The present invention also provides an improved method of calibraating a dynamic balancing machine for detecting mass unbalance in objects mounted on a rotatably driven machine shaft, said method being as defined in claim 4.

The present invention also provides an improved method of calibrating a dynamic mass unbalance detection machine having a shaft rotably driven about a spin axis, said method being as defined in claim 10.

Brief description of the drawings

Figure 1 is a diagrammatic elevation view of the unbalance measurement system of the present invention.

Figure 2 is a graphic depiction of the relationship between force and sensor output as a function of axial shaft position.

Description of the preferred embodiments

The invention disclosed herein is for use in a dynamic balancing machine, typified by the conventional mechanical arrangement shown in U.S. Patent 4,285,240 mentioned previously. The machine pr vides for measurement of unbalance

mass in a rotating body when the unbalance mass produces an unbalance force when the body is rotat d by the machine. Typically an automobile rim and tire c mbinati n provides th article t be balanced. The rim and tire combination is securely mounted against a shoulder on a spin shaft in the machine. The rim portion of the rim and tire combination has the usual centrally disposed hole which fits over the end of the shaft and the rim is held tightly in place on the shaft by a wheel clamp which engages threads formed on the shaft end. A pair of bearing housings are supported within machine framework. Bearing members within the bearing housings support the shaft within the framework so that the shaft is disposed for rotational motion within the framework. Left and right force transducers are positioned between the framework and the bearing housings and the transducers are maintained in continuous contact with the housings. In this fashion forces arising by reason of rotation of an unbalanced article mounted on the machine shaft are sensed by the transducers and electrical outputs are provided thereby.

The machine also includes structure associated with the shaft for providing data indicative of the instantaneous position of the shaft. The shaft is driven by a motor through a belt and pulley arrangement. Controls are provided for initiating rotation in the shaft as well as for selecting the various functions performed by the machine, such as operations to detect unknown unbalance, to obtain transducer calibration or to detect zero shaft unbalance, to name a few. Other functions are described in the aforementioned U.S. Patent 4,285,240.

A phasor is defined as an alternating quantity conveniently represented by a projection of a rotating line on a fixed axis. The unbalance forces caused by rotation of an unbalanced mass mounted on the machine will be described herein as phasors, wherein they will be conveniently represented by instantaneous projections of the phasor on orthogonal x and y axes. Unbalance phasors may be caused by unknown mass unbalance in a rotating body being measured, known calibration weight mass unbalance, or unloaded or free running shaft unbalance as the shaft is rotated. Fundamental x and y components of the rotating mass unbalance phasors may be recovered substantially noise free and measured as described in the aforementioned U.S. Patent 4,285,240. With this in mind, the unbalance measurement equations for a rotating body will be reviewed presently.

By way of review of the pertinent portion of the machine, Figure 1 shows a shaft 11 mounted in a framework represented at 12. The shaft may be selectively driven rotationally through a pulley 13 fixed to the shaft, a belt 14 surrounding the pulley and engaging a pulley 16 on the end of a shaft which is driven by a frame mounted motor 17. The shaft is mounted in bearings within the framework as h reinbefore described, and left and right forc sensors or transducers 18 and 19 resp ctively ar mechanically coupled to the shaft. Force exerted n the left transducer is shown as F_L and on the right transducer as F_R. The axial spacing between the left and right force sensors (Z_0 to Z_3) is shown as a. A pair of mass unbalance correction planes P2 and P1 are shown in Figure 1 intersecting the axis of the shaft at points Z_4 and Z_5 respectively. The unbalance correction planes are separated by a distance c and the left correction plane P2 is displaced by the distance b from the axial location Z_3 of the right transducer 19. Dynamic unbalance measurement is obtained for an article for which mass unbalance has been detected by converting the sensed unbalance data to unbalance correction weight to be applied at a point in each of the correction planes, so that not only radially directed mass unbalance is compensated, but unbalance couples about an axis orthogonal to the spin axis are also compensated.

It may also be seen in Figure 1 that a pair of mass unbalance calibration planes Z_2 and Z_1 intersecting the shaft spin axis are shown separated by a distance e. The left calibration plane Z_2 is spaced from the right transducer 19 at Z_3 by a distance d. Calibration forces F_{C1} and F_{C2} are shown in the calibration planes Z_2 and Z_3 respectively. The manner in which these calibration forces are obtained and the purpose to which they are put will be hereinafter described. It should be noted that the calibration planes Z_2 and Z_1 are shown as displaced from the unbalance correction planes P2 and P1 in Figure 1 for illustrative purposes only. The unbalance calibration planes may take various positions relative to the unbalance correction planes, ranging from coincidence with typical unbalance correction planes to positions to the left or right (as shown), or any intermediate positions therebetween. It should be noted in Figure 1 that the vertical direction may be denoted the y direction, the direction orthogonal to the plane of the paper the x direction, and the horizontal direction the z direction.

With reference now to Figure 2 of the drawings, the horizontal axis is also designated the z axis and corresponds to the center line of the shaft 11. The vertical axis in Figure 2 is designated the y axis; and the axis orthogonal to the plane of the paper is designated the x axis. The left and right transducers or forces sensors, 18 and 19 respectively, are shown in Figure 2. Mass unbalance correction planes P2 and P1 and mass unbalance calibration planes Z_2 and Z_1 are shown in Figure 2 in the same relative positions they occupy in Figure 1. The force exerted on the left force transducer 18, F_L and the force exerted on the right force transducer 19, F_R, are shown exerted at shaft axial positions Z_0 and Z_3 respectively.

It should be noted that shaft angle is known at any point in time and therefore the x and y c mp n nts of the unbalance force phasors (and therefore th transducer utput signal phasors) are attainabl at any point in tim . In the

following, the symbols $\bar{F}$, $\bar{E}$ and $\bar{K}$ will be used to represent the force, transducer utput signal and correction phasors respectively. The correction phasor is required because experience t aches that the transducer output is not quite in phase with the force exerted thereagainst, and the output magnitude is not exactly the same from transducer to transducer. The correction phasor is therefore necessary to provide phase and scale factor correction for the transducer output signals.

In complex exponential notation the following relationships apply:

$$\bar{F}=Fe^{j\omega t}$$

$$\bar{E}=Ee^{j(\omega t-\theta)}$$

If

$$\bar{K}=Ke^{j\theta} \text{ and } KE=F$$

Then

$$\bar{K}\bar{E}=KEe^{j\omega t}=Fe^{j\omega t}=\bar{F} \quad (1)$$

We have therefore defined the correction constant $\bar{K}$.

Choosing the transducer output phasor $\bar{E}$ for this example to lag in phase behind the force phasor $\bar{F}$, the relationships (1) may be expanded as follows:

$$\bar{F}=KEe^{j\omega t}=KE\ (\cos\omega t+j\sin\omega t)$$

$$\bar{F}=(K_x+JK_y)\ (E_x-JE_y)$$

And

$$K_x+JK_y=\frac{F(E_x+JE_y)}{E_x^2+E_y^2} \quad (2)$$

For one transducer extracting real components provides the following relationship:

$$K_x=\frac{FE_x}{E_x^2+E_y^2} \quad (3)$$

Extracting imaginary components from the relationship (2) provides the following:

$$K_y=\frac{FE_y}{E_x^2+E_y^2} \quad (4)$$

Expanding both sides of relationship (1) provides the following relationship:

$$\bar{F}=F_x+JF_y=(K_x+JK_y)\ (E_x-JE_y)$$

$$=K_xE_x+K_yE_y+J\ (K_yE_x-K_xE_y) \quad (5)$$

Extracting real components from relationship (5) provides the following:

$$F_x=K_xE_x+K_yE_y \quad (6)$$

Extracting imaginary components from the relationship (5) provides the following:

$$F_y=K_yE_x-K_xE_y \quad (7)$$

It should be noted that relationships 6 and 7 are for one transducer only.

Referring now to Figure 2, a general solution for F_L, F_R, F'_L and F'_R is undertaken together with an explanation of the advantages obtained by computing the latter two quantities. As disclosed in the U.S. Patent 4, 285,240 to which reference is made hereinbefore, calibration of the transducers 18 and 19 is undertaken by rotating a single known unbalance on the shaft 11 at, in this example, the plane Z_2 seen in Figure 2. When such a calibration spin is undertaken, the forces F_L, F_R and F_{C2} are present in planes substantially orthogonal to the axis of shaft 11 at points Z_0, Z_3 and Z_2 respectively. A summation of the forces (with upwardly directed forces being positive) results in the following:

$$-F_L+F_R-F_{C2}=0$$

$$F_R=F_L+F_{C2}$$

A summation of the moments about Z_3 (with clockwise moments assigned a positive sense) results in the following:

$$-F_Ka+F_{C2}d=0$$

$$F_L=\left(\frac{d}{a}\right)F_{C2} \quad (8)$$

$$F_R=\left(\frac{d}{a}+1\right)F_{C2} \quad (9)$$

The relationships (8) and (9) result. These relationships may be seen to be straight line or linear relationships in Figure 2 extending from the point E_{LC2} to the point Z_3 (8), and extending from the point E_{RC2} to the point Z_0 (9). These linear relationships are shown in dashed lines in Figure 2 and may be seen to be functions of known dimensions in the z direction as well as the known calibration force, F_{C2}.

The actual relationship between force and transducer output as the plane in which an unbalance weight moves in the z direction is shown by the curves 21 and 22 for the right and left transducers respectively in Figure 2. These curves are obtained by mounting known calibration weights on the shaft at known axial positions and observing the transducer outputs.

The curve 21 is generated by looking at the output of the right transducer 19 as a calibration weight is positioned at a plurality of points along the z axis. The left end of the curve 21 appears as a dashed line because axial test point locations for the calibrati n weight g only just to th left of the right transducer 19 in actual practic .

Therefore the curve 21 is extrapolated to the point Z_0 at the axial location of the l ft transducer. It may be seen intuitively that F_R would have't be zero if the calibration weight was placed in a plane indlucing Z_0, becaus th oretically all of the unbalance would be sensed by the left transducer 18.

The actual curve 22 for F_L is generated in the same fashion as is used to generate curve 21. Again, if all of the calibration weight was in the plane including point Z_3 the output from transducer 18 would be zero and all the output would be provided by the right transducer 19. The curves may be seen to be concave upwardly and to depart to some extent from the straight line relationships (8) and (9). As a consequence, it may be seen that the value on the line representing the last two mentioned relationships is an approximation and departs from the actual relationships 21 or 22 at the mass unbalance correction plane P2. This departure or deviation represents an error imposed in the measured unbalance in plance P2.

As mentioned previously the mass unbalance calibration planes Z_2 and Z_1 are shown in Figure 2 displaced from mass unbalance correction planes P2 and P1 for purposes of clarity. Calibration planes may be positioned at other intersections with the z axis of Figure 2 and could be made to coincide with unbalance correction planes P2 and P1. An unbalance weight calibration fixture is shown in dashed lines in Figure 1 having known calibration weights W1 and W2 mounted thereon in calibration planes Z_1 and Z_2 and at known radii from the spin axis of shaft 11. However, since the unbalance correction planes P2 and P1 depend upon the configuration of the article being balanced, the points Z_4 and Z_5 will change in position on the z axis from article to article.

When known calibration weights are spun on the shaft 11 in one of the planes Z_1 or Z_2 and then the other, the left transducer 18 provides an output E_{LC1} and E_{LC2} and the right transducer 19 provides an output E_{RC1} and E_{RC2}. Since the positions Z_1 and Z_2 are known, the calibration forces F_{C2} and F_{C1} are known, and the aforementioned transducer outputs are measured, the z direction dimensions a' and d' seen in Figure 2 may be defined as follows:

$$\frac{E_{LC2}}{d'} = \frac{E_{LC1}}{d'+e}$$

$$d' = \frac{eE_{LC2}}{E_{LC1} - E_{LC2}} \quad (10)$$

$$\frac{E_{RC1}}{a'+d'+e} = \frac{E_{RC2}}{a'+d'}$$

$$a' = -d' + e\frac{E_{RC2}}{E_{RC1} - E_{RC2}} \quad (11)$$

By analogy to relationships (8) and (9), the following relationships for F'_L and F'_R may be made

$$F'_L = \frac{d'}{a'} F_{C2} \quad (12)$$

$$F'_R = (1 + \frac{d'}{a'}) F_{C2} \quad (13)$$

$$F'_L = F_{C2}\left(\frac{E_{LC2}(E_{RC1} - E_{RC2})}{E_{RC2}E_{LC1} - E_{LC2}E_{RC1}}\right) \quad (14)$$

$$F'_R = F_{C2}\left(1 + \frac{E_{LC2}(E_{RC1} - E_{RC2})}{E_{RC2}E_{LC1} - E_{LC2}E_{RC1}}\right) \quad (15)$$

Relationships (14) and (15) shown that F'_L and F'_R are functions of a known calibration force F_{C2} and measured transducer output values E.

The straight line functions (12) and (13) are shown in Figure 2 as F'_R and F'_L extending through the points (E_{RC1}, E_{RC2}) and (E_{LC1}, E_{LC2}) respectively. These straight line relationships intersect the z axis at Z'_0 and Z'_3, which represent the apparent locations of the transducers 18 and 19. Their apparent separation in the z direction is a' and the apparent distance in the z direction from Z'_3 to Z_2 is noted as d'. Thus, the apparent axial separation between the transducers 18 and 19 and the apparent axial positions of th transducers relative to the calibration plane through the point Z_2 are known. The deviation of the relationships F'_R and F'_L from the actual curves 21 and 22 in the unbalance correction plane P2 may be seen to be considerably less than the deviation of the straight lines F_R and F_L from curves 21 and 22 in plane P2. Therefore the error content in detected unbalance in the mass unbalance correction planes is reduced.

Alternatively relatively precise calibration for the transducers 18 and 19 may be obtained for specific mass unbalance correction planes P2 and P1 by taking the calibration data while one unbalance calibration plane is coincident with plane P2 and the other is coincident with plane P1. This procedure would require a calibration run for each set of mass unbalance correction planes P2 and P1.

As shown, the straight line relationships for F'_L and F'_R are good approximations of the curves 22 and 21 respectively in the regions from Z_4 through Z_1. If higher degress of accuracy are required, then the straight line approximations F'_R and F'_L could give way to construction of the actual curves 21 and 22 by undertaking a sufficiently large number of calibration spins with th calibration weight being moved incrementally in the z direction. Precise calibration data could then be obtained for any axial location of mass unbalance correction planes P2 and P1.

The lin ar relationships F'_R and F'_L appear

practically parallel in that portion of the curves depicted in Figur 2, but may be seen from the relati nships themselves to converge at infinity.

The calibration constants themselves are obtained by combining relationships (3) and (12) and by combining the relationships (4) and (13). The following results are obtained:

$$\left.\begin{aligned} K_{LX} &= \frac{(d'/a')F_{cz}E_{LXC}}{E^2_{LXC}+E^2_{LYC}} \\ K_{LY} &= \frac{(d'/a')F_{cz}E_{LYC}}{E^2_{LXC}+E^2_{LYC}} \\ K_{RX} &= \frac{(1+d'/a')F_{cz}E_{RXC}}{E^2_{RXC}+E^2_{RYC}} \\ K_{RY} &= \frac{(1+d'/a')F_{cz}E_{RYC}}{E^2_{RXC}+E^2_{RYC}} \end{aligned}\right\} \quad (16)$$

In the relationships (16) it should be noted that there are x and y components for the calibration constants for the left transducer 18 and the right transducer 19. The quantity E_{LXC} for example, describes the x component of the left transducer output with the calibration weight in unbalance calibration plane Z_2.

Applying the calibration constants of the relationships (16) to the general force transducer equations for the x and y components, (6) and (7) respectively, the following is obtained:

$$\left.\begin{aligned} F_{LX} &= K_{LX}E_{LX}+K_{LY}E_{LY} \\ F_{LY} &= K_{LY}E_{LX}-K_{LX}E_{LY} \\ F_{RY} &= K_{RX}E_{RX}+K_{RY}E_{RY} \\ F_{RX} &= K_{RY}E_{RX}-K_{RX}E_{RY} \end{aligned}\right\} \quad (17)$$

It may therefore be seen that the calibration constants obtained by the use of the foregoing described apparatus and method may be applied to the transducer data to obtain data indicative of the unbalance force in an article being spun on the shaft 11, which data is thereby corrected for errors in the transducer output due to transducer idiosyncrasies and physical placement along the shaft relative to the mass unbalance correction planes.

If the shaft assembly 11 is not mechanically balanced (for example by means of turning the shaft assembly itself on a balancer and removing shaft assembly material to obtain dynamic balance) a zero balance spin, or unloaded shaft spin may be undertaken as described in the aforementioned U.S. Patent 4,285,240. The residual shaft unbalance quantities may be stored for use in removing th effects of such residual unbalance from data obtained in the machine calibration steps described herein or from unknown unbalance measurements tak n for articles being balanced. If E_{LXCU} and similar tems correspond to E_{LXC} and similar terms uncalibrated, and if E_{LXCO} is E_{LX} with no shaft l ad, then:

$$\left.\begin{aligned} E_{LXC} &= E_{LXCU}-E_{LXCO} \\ E_{LYC} &= E_{LYCU}-E_{LYCO} \\ E_{RXC} &= E_{RXCU}-E_{RXCO} \\ E_{RYC} &= E_{RYCU}-E_{RYCO} \end{aligned}\right\} \quad (18)$$

In like fashion where E_{LXU} and similar terms correspond to E_{LX} and similar terms uncalibrated, then:

$$\left.\begin{aligned} E_{LX} &= E_{LXU}-E_{XCO} \\ E_{LY} &= E_{LYU}-E_{LYCO} \\ E_{RX} &= E_{RXU}-E_{RXCO} \\ E_{RY} &= E_{RYU}-E_{RYCO} \end{aligned}\right\} \quad (19)$$

It should be noted that in the relationships (18) and (19) the quantities on the left of the relationships are calculated from the quantities on the right which are measured.

The manner in which the data acquired by means of the description herein is transposed to the mass unbalance correction planes P2 and P1 for indication of unbalance measurements in those planes, and the computation of the compensating weights and angular positions for weight applications in the correction planes is described in the aforementioned U.S. Patent 4,285,240, columns 8, 9 and 10.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from what is claimed.

Claims

1. Apparatus for calibrating a balancing machine for dynamically balancing objects rotatable on a shaft thereon, comprising

means for mounting a known mass at a known radial position and at a first known axial position on the shaft,

means for mounting a known mass at a known radial position and at a second known axial position on the shaft,

a pair of sensors for detecting force spaced along and coupled to the shaft for detecting force caused by mass unbalance mounted on the shaft when it is rotating,

means coupled to said sensor means for computing the mass unbalance during a first calibration spin with said known mass in said first axial position and during a second calibration spin with said known mass in said second axial

position and for comparing the computed with the known mass unbalances, when said known masses are sequentially m unted on the machine, whereby correction factors for a specific sensor means is obtainable from the comparison.

2. Apparatus as in claim 1 wherein said mounting means comprise a wheel rim-like fixture adapted to be mounted on the shaft and a plate attached to the periphery thereof having a plurality of axially spaced mounting positions thereon and providing first and second known axial positions.

3. Apparatus as in claim 1 wherein said means for mounting comprise first and second separate plates alternatively mountable on the shaft.

4. A method of calibrating a dynamic balancing machine for detecting mass unbalance in objects mounted on a rotatably driven machine shaft, wherein a pair of sensors for detecting force are spaced along and coupled to the shaft and provide outputs indicative of unbalance during shaft rotation, and wherein the sensor outputs are coupled to a computer which provides unbalance force magnitude and phase information, comprising the steps of

mounting a known mass at a known radius and a first known axial position on the shaft,

spinning the shaft a first time,

storing the sensor outputs,

mounting a known mass at a known radius and a second known axial position on the shaft,

spinning the shaft a second time to obtain further sensor outputs,

computing the apparent axial separation between the sensors and the apparent axial positions of the sensors utilizing the outputs obtained from the first and second shaft spins, whereby magnitude and phase information with reduced error content is detectable relative to unbalance mass in machine shaft mounted objects at predetermined axially located planes, said apparent axial positions of the sensors being determined by using a straight line relationship in the computation of the outputs obtained for each of said pair of sensors during said first and second shaft spins as a function of said first and second axial shaft positions, the points at which said straight line relationships pass through a reference line representing axial position on the shaft being termed the apparent axial positions of the sensors.

5. A method as in claim 4 together with the steps of spinning the shaft with no load mounted thereon, storing the no load sensor outputs, and correcting the outputs from the first and second shaft spins with the no load outputs.

6. A method as in claim 4 wherein the steps of mounting known masses at first and second known axial positions comprise the steps of selecting the first and second axial positions to be substantially in the predetermined axially located unbalance mass detection planes.

7. A method as in claim 4 wh rein the shaft is rotatably driv n about a spin axis and the sensors are force sensors providing outputs indicative of force r sulting from unbalance loads during shaft rotation and wherein th outputs ar lectrically coupled to said computer, comprising the steps of

mounting a known mass on the shaft at a known radius from the spin axis and in a first known mass unbalance calibration plane,

spinning the shaft a first time,

storing data indicative of the first spin force sensor outputs,

mounting a known mass on the shaft at a known radius from the spin axis and in a second known mass unbalance calibration plane,

spinning the shaft a second time to obtain further sensor outputs, and computing the apparent axial separation and axial positions of the sensors using the data indicative of the force sensor outputs from the first and second spins, whereby such computed quantities are used to reduce the error content in detected unbalance in predetermined mass unbalance correction planes.

8. A method as in claim 7 together with the steps of spinning the shaft with no load mounted thereon, storing the no load sensor data, and correcting the data from the first and second shaft spins with the no load data.

9. A method as in claim 6 wherein the steps of mounting known masses in first and second known mass unbalance calibration planes comprise the steps of selecting the first and second calibration plane and locations to be substantially in the predetermined mass unbalance correction planes.

10. A method of calibrating a dynamic mass unbalance detection machine having a shaft rotatably driven about a spin axis and a pair of force sensors providing outputs indicative of force resulting from unbalance loads during shaft rotation and being axially spaced along and mechanically coupled to the shaft, wherein the outputs are electrically coupled to a computer, comprising the steps of

mounting a known mass on the shaft at a known radius from the spin axis and in a plurality of successive known axially spaced mass unbalance calibration planes,

spinning the shaft a plurality of times, once for each of the axially spaced calibration planes,

storing data indicative of the force sensor outputs from each calibration plane spin, and

computing the relationships between unbalance force and data indicative thereof as a function of axial shaft position using the data indicative of the force sensor outputs from the plurality of spins, whereby such computed relationships may be used to provide calibration data to reduce the error content in detected unbalance in predetermined mass unbalance correction planes.

11. A method as in claim 10 wherein the step of computing comprises calling up the calibration data from the computed relationships which correspond to the axial shaft position of the mass unbalance correction planes.

12. A method as in claim 11 wherein the

calibration data are obtained in two calibration planes and the computed relationships are assumed to be linear.

13. A method as in claim 10 together with the steps of spinning the shaft with no load mounted thereon, storing the no load sensor data, and correcting the stored data with the no load data.

Patentansprüche

1. Vorrichtung zum Kalibrieren einer Maschine zum dynamischen Auswuchten von Gegenständen, die auf einer Welle auf ihr drehbar angeordnet sind, gekennzeichnet durch

eine Einrichtung zum Anbringen einer bekannten Masse in einer bekannten radialen und in einer ersten bekannten axialen Lage an der Welle,

durch eine Einrichtung zur Anbringung einer bekannten Masse in einer bekannten radialen und einer zweiten bekannten axialen Lage an der Welle,

durch ein Paar Sensoren zur Ermittlung von Kräften, die auf der Welle beabstandet und mit ihr gekoppelt sind, um Kräfte zu erfassen, die durch die Massenunwucht an der Welle bei deren Drehung auftreten, und

durch ein an die Sensoranordnung angeschlossene Einrichtung zum Berechnen der Massenunwucht während einer ersten Kalibrierdrehung, bei welcher sich die bekannte Masse in der ersten axialen Lage befindet, und während einer zweiten Kalibrierdrehung, bei welcher sich die bekannte Masse in der zweiten axialen Lage befindet, und zum Vergleich der berechneten mit der bekannten Massenunwucht, wenn die bekannten Massen nacheinander auf Maschine angebracht werden, so daß aus dem Vergleich Korrekturfaktoren für eine spezielle Sensoranordnung ableitbar sind.

2. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die Einrichtung zum Anbringen eine felgenartige Einrichtung, die auf die Welle aufsettbar ist, sowie eine an deren Umfang angebrachte Platte, mit einer Vielzahl axial beabstandeter Anbringpositionen aufweist, welche die erste und die zweite bekannte axiale Lage schafft.

3. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die Einrichtung zum Anbringen eine erste und eine zweite Platte aufweist, die alternative auf die Welle aufsetzbar sind.

4. Verfahren zum Kalibrieren einer dynamischen Auswuchtmaschine zum Ermitteln der Massenunwucht von auf einer drehangetreibenen Maschinenwelle aufgesetzten Gegenständen, wobee ein Paar Sensoren zur Ermittlung von Kräften entlang der Welle beabstandet und mit dieser gekoppelt ist und während der Wellendrehung die Unwucht anzeigende Ausgangssignale liefert, wobei die Sensor-Ausgangssignal an ein n Rechner gelegt werden, der Amplituden- und Phaseninformation hinsichtlich der Unwucht liefert, dadurch gekennzeichnet, daß

eine bekannte Masse in einer bekannten radialen und einer ersten bekannten axialen Lage auf der Well angeordnet wird,

die Welle ein erstes Mal gedreht wird,

die Sensor-Ausgangssignale abgespeichert werden,

eine bekannte Masse in einer bekannten radialen und einer zweiten bekannten axialen Lage auf der Welle angeordnet wird,

die Welle ein zweites Mal gedreht wird, um weitere Sensor-Ausgangssignale zu erhalten, und daß

aus den Ausgangssignalen für die erste und die zweite Wellendrehung der scheinbare axiale Abstand zwischen den Sensoren und deren scheinbare axiale Positionen berechnet werden, wodurch Amplituden- und Phaseninformationen mit verringertem Fehleranteil über die Unwucht von auf der Maschinenwelle in vorbestimmten Axialebenen angebrachten Gegenständen erhältlich sind, wobei die scheinbaren axialen Positionen der Sensoren bei der Rechnung der bei der ersten und der zweiten Wellendrehung erhaltenen Sensor-Ausgangssignale unter Ansatz eines gradlinigen Zusammenhangs zwischen der ersten und der zweiten axialen Lage auf der Welle bestimmte werden und die Punkte, in denen die Gerade die axiale Lage entlang der Welle darstellende Bezugslinien schneidet, als die scheinbaren axialen Orte der Sensoren gelten.

5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß die Welle ohne aufgesetzte Last gedreht wird, diese Leerlauf-Ausgangssignale der Sensoren gespeichert und die Ausgangssignale für die erste und die zweite Wellenumdrehung mit den Leerlauf-Ausgangssignalen korrigiert werden.

6. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß bei der Anbringung der bekannten Massen in der ersten und der zweiten bekannten axialen Lage diese axialen Lagen so gewählt werden, daß sie sich im wesentlichen in den vorbestimmten axialen Unwucht-Ermittlungsebenen befinden.

7. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß die Welle um eine Spin- bzw. Umdregungsachse drehbar angetrieben wird und die Sensoren Kraftsensoren sind und Ausgangssignale liefertn, die die infolge der Unwuchtbelastung bei der Wellendrehung entstehenden Kräfte anzeigen, daß die Ausgangssignale elektrisch an den Rechner angeschlossen sind,

daß eine bekannte Masse auf der Welle in einem bekannten Radius von der Umdrehungsachse und in einer ersten bekannten Unwicht-Kalibrierungsebene angeordnet wird,

die Welle ein erstes Mal gedreht wird,

die den bei der ersten Drehung auftretenden Sensor-Ausgangssignalen entsprechenden Daten abgespeichert werden,

einen bekannte Masse auf der Welle in einem bekannten Radius von der Umdrehungsachse und in einer zweiten bekannten Unwucht-Kalibrierungsebene angeordnet wird,

und daß die Welle ein zweites Mal gedreht wird,

um weitere Sensorausgangssignale zu erhalten, aus denen die Ausgangssignale der Kraftsensoren beim ersten und beim zweiten Drehen darstellenden Daten den scheinbaren axialen Abstand und die axiale Lage der Sensoren berechnet und mit den berechneten Größen der Fehleranteil der ermittelten Umwucht in vorbestimmten Unwucht-Korrekturebenen verringert werden.

8. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß die Welle ohne Last gedreht wird, daß diese Leerlauf-Sensordaren abgespeichet werden, und daß die Daten aus dem ersten und dem zweiten Drehen der Welle mit den Leerlaufdaten korrigiert werden.

9. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß das Anbringen bekannter Massen in einer ersten und einer zweiten bekannten Unwucht-Kalibrierungsebene das Auswählen der ersten und der zweiten Kalibrierungsebene und -orte im wesentlichen als in den vorbestimmten Unwucht-Korrekturebenen liegend umfaßt.

10. Verfahren zum Kalibrieren einer Maschine zum dynamischen Erfassen von Unwuchten, die eine um eine Umdrehungsachse drehangetriebene Welle und ein Paar Kraftsensoren aufweist, welche Ausgangssignale entsprechend den von der Unwucht bei der Wellendrehung verursachten Kräfte liefern und die entlang der Welle axial beabstandet und mit ihr gekoppelt sind, wobei die Ausgangssignale elektrisch an einen Rechner gelegt sind, dadurch gekennzeichnet, daß

eine bekannte Masse auf der Welle in einem bekannten Radius von der Umdrehungsachse und in einer Vielzahl aufeinanderfolgender axial beabstandeter Unwucht-Kalibrierungsebenen angeordnet wird,

die Welle eine Vielzahl von Malen, und zwar jeweils einmal für jede der axial beabstandeten Kalibrierungsebenen gedreht wird,

den Ausgangssignalen der Kraftsensoren für jede der Umdrehunden in den Kalibrierungsebenen entsprechende Daten abgespeichert werden, und

aus den den Ausgangssignalen der Kraftsensoren für die Umdrehungen entsprechenden Daten die Zusammenhänge zwischen der Unwucht und den dieser entsprechenden Daten als Funktion der axialen Lage entlang der Welle berechnet werden, so daß aus den berechneten Zusammenhängen Kalibrierungsdaten abgeleitet werden, mit denen der Fehleranteil der erfaßten Unwucht in vorbestimmten Unwucht-Korrekturebenen verringert werden kann.

11. Verfahren nach Anspruch 10, dadurch gekennzeichnet, daß das Berechnen das Ermitteln der Kalibrierungsdaten aus den berechneten Zusammenhängen umfaßt, die der axialen Lage der Unwucht-Korrekturebenen entlang der Welle entsprechen.

12. Verfahren nach Anspruch 11, dadurch g kennzeichnet, daß die Kalibrierungsdaten in zwei Kalibrierungsebenen aufgenommen und die berechneten Zusammenhänge als linear angenommen werden.

13. V rfahren nach Anspruch 10, dadurch gekennzeichnet, daß die Welle ohne aufgesetzte Last g dreht wird, daß diese Leerlauf-Sensordaten abgespeichert w rden und daß die abgespeich rten Daten mit den Leerlaufdaten korrigiert werden.

Revendications

1. Appareil d'étalonnage d'une machine d'équilibrage destiné à équilibrer dynamiquement des objets tournant sur un arbre, comportant:

un dispositif de montage d'une masse connue dans une position radiale connue et dans une première position axiale connue sur l'arbre,

un dispositif de montage d'une masse connue dans une position radiale connue et une second position axiale connue sur l'arbre,

une paire de capteurs destinés à détecter une force, espacés le long de l'arbre et accouplés avec lui pour détecter une force produite par un déséquilibre de masse montée sur l'arbre lorsqu'il est en rotation,

un dispositif couplé avec lesdits capteurs pour calculer le déséquilibre de masse pendant une première rotation d'étalonnage avec ladite masse connue dans ladite première position axiale et pendant une seconde rotation d'étalonnage avec ladite masse connue dans ladite second position axiale et pour comparer le déséquilibre calculé avec le déséquilibre de masse connu lorsque lesdites masses connues sont montées séquentiellement sur la machine de manière que des facteurs de correction pour un dispositif capteur spécifique puissent être obtenus à partir de la comparaison.

2. Appareil selon la revendication 1, dans lequel ledit dispositif d'un montage comporte un accessoire en forme de jante de roue agencé pour être monté sur l'arbre et une plaque fixée sur sa périphérie comprenant plusieurs positions de montage espacées axialement et déterminant une première et une seconde positions axiales connues.

3. Appareil selon la revendication 1, dans lequel ledit dispositif d'un montage comporte une première et une seconde plaques séparées pouvant être montées alternativement sur l'arbre.

4. Procédé d'étalonnage d'une machine d'équilibrage dynamique destiné à détecter un déséquilibre de masse dans des objets montés sur un arbre de machine mis en rotation, dans lequel une paire de capteurs pour détecter une force sont espacés le long de l'arbre et accouplés avec lui et fournissent des sorties indiquant un déséquilibre pendant une rotation de l'arbre, et dans lequel les sorties des capteurs sont couplées avec un calculateur qui produit des informations d'amplitude et de phase de force de déséquilibre, consistant essentiellement:

à monter une masse connue à un rayon connu et une première position axiale connue sur l'arbre,

à faire tourner l'arbre une première fois,

à mémoriser les sorties des capteurs,

à monter une masse connue avec un ray n connu et une seconde position axiale connue sur l'arbre,

à faire tourner l'arbre une seconde fois pour obtenir d'autres sorties des capteurs,

à calculer la séparation axiale apparente entre les capteurs et les positions axiales apparentes des capteurs en utilisant les sorties obtenues à partir de la première et la seconde rotations d'arbre, de manière que des informations d'amplitude et de phase avec un contenu d'erreurs réduit puissent être détectées par rapport à une masse de déséquilibre dans des objets montés sur l'arbre de machine à des plans prédéterminés situés axialement, lesdites positions axiales apparentes des capteurs étant déterminées en utilisant une relation rectiligne dans le calcul de sorties obtenues pour chacune desdites paires de capteurs pendant ladite première et ladite seconde rotations d'arbre en fonction de ladite première et ladite seconde positions axiales d'arbre, les points auxquels lesdites relations rectilignes passent par une ligne de référence représentant une position axiale sur l'arbre étant considérés comme les positions axiales apparentes des capteurs.

5. Procédé selon la revendication 4, associé avec les opérations de mise en rotation de l'arbre sans aucune charge montée sur lui, de mémorisation des sorties des capteurs en l'absence de charge et de correction de sorties à partir de la première et la seconde rotations d'arbre sans aucune sortie de charge.

6. Procédé selon la revendication 4, dans lequel les opérations de montage de masses connues dans la première et la seconde positions axiales connues consistent à sélectionner la première et la seconde positions axiales pour qu'elles se situent dans des plans prédéterminés de détection de masse de désaquilibre situés axialement.

7. Procédé selon la revendication 4, dans lequel l'arbre est entraîné en rotation autour d'un axe de rotation et les capteurs sont des capteurs de force produisant des sorties indiquant une force résultant de charges de déséquilibre pendant la rotation de l'arbre et dans lequel les sorties sont appliqués électriquement audit calculateur, consistant en outre:

à monter une masse connue sur l'arbre avec un rayon connu par rapport à l'axe de rotation et dans un premier plan d'étalonnage de déséquilibre de masse connu,

à faire tourner l'arbre une première fois,

à mémoriser des données indiquant les premières sorties de capteurs de force de rotation,

à monter une masse connue sur l'arbre avec un rayon connu par rapport à l'axe de rotation et dans un second plan d'étalonnage de déséquilibre de masse connu,

à faire tourner l'arbre une second fois pour obtenir d'autres sorties des capteurs et à calculer la séparation axiale apparente et les positions axiales apparentes des capteurs en utilisant les d nnées indiquant les sorties des capteurs de force à la première et la seconde rotations d manière que ces quantités calculées soient utilisées pour réduire le contenu d'erreurs dans le déséquilibre détecté dans des plans prédéterminés de correction de déséquilibre de masse.

8. Procédé selon la revendication 7, associé avec les opérations de mise en rotation de l'arbre lorsqu'aucune charge n'est montée sur lui, de mémorisation des données des capteurs sans charge et de correction des données à partir de la première et la seconde rotations d'arbre avec les données en l'absence de charge.

9. Procédé selon la revendication 6, dans lequel les opérations de montage de masses connues dans le premier et le second plans d'étalonnage de déséquilibre de masses connues consistent à sélectionner le premier et le second plans d'étalonnage et les positions pour qu'ils soient pratiquement dans les plans prédéterminés de correction de déséquilibre de masse.

10. Procédé d'étalonnage d'une machine de détection de déséqulibre de masse dynamique comportant un arbre mis en rotation autour d'un axe de rotation et une paire de capteurs de force produisant des sorties indiquant une force résultant de charges de déséquilibre pendant une rotation de l'arbre et étant espacés axialement le long de l'arbre et accouplés mécaniquement avec lui, dans lequel les sorties sont couplées électriquement avec un calculateur, consistant:

à monter une masse connue sur l'arbre avec un rayon connu par rapport à l'axe de rotation et dans plusieurs plans d'étalonnage de déséquilibre de masse d'espacement axial connu, successifs,

à faire tourner l'arbre plusieurs fois, une fois pour chacun des plans d'étalonnage espacés axialement,

à mémoriser des données indiquant les sorties des capteurs de force à partir de chaque rotation de plan d'étalonnage,

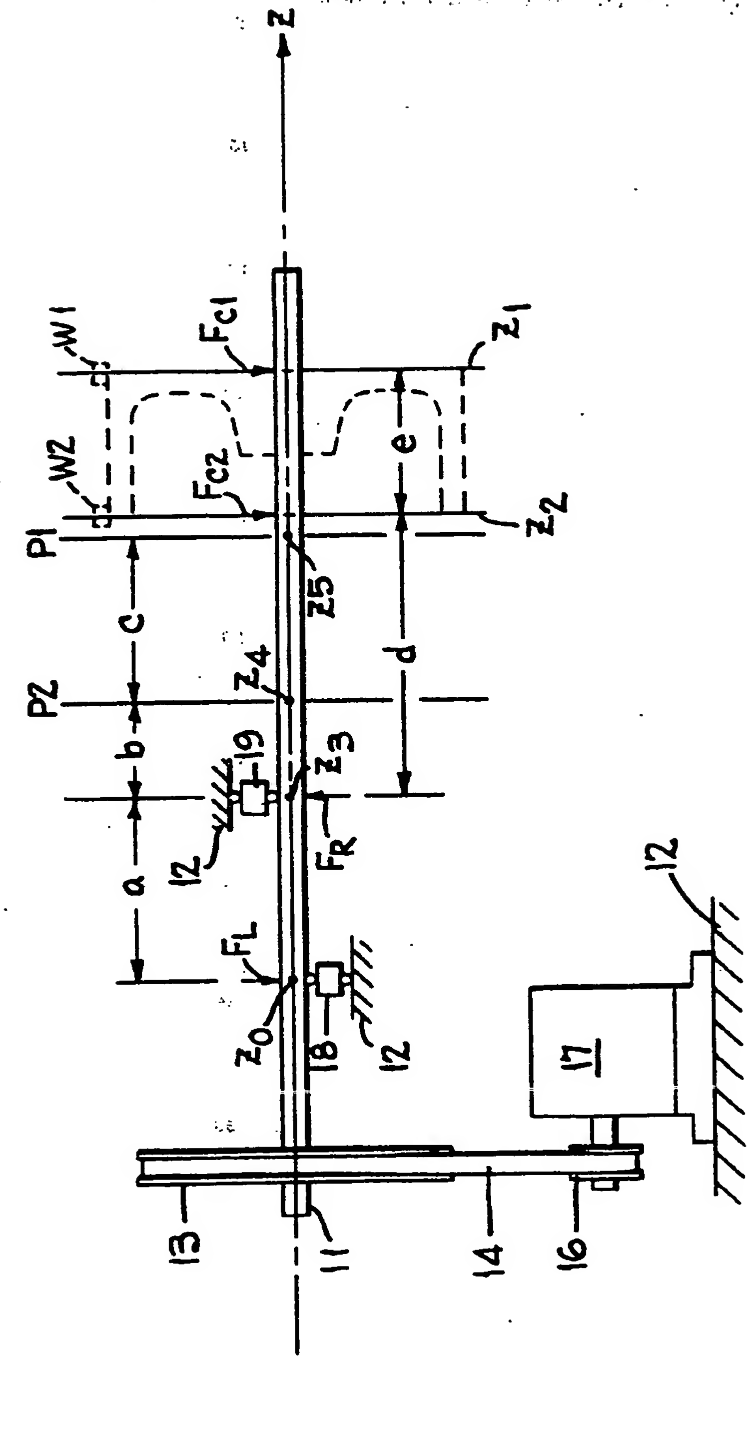
et à calculer les relations entre la force de déséquilibre et des données les indiquant en fonction de la position axiale de l'arbre en utilisant les données indiquant les sorties de capteurs de force à partir de plusieurs rotations, de manière que ces relations calculées puissent être utilisées pour produire des données d'étalonnage de manière à réduire la teneur en erreur dans le déséquilibre détecté dans des plans prédéterminés de correction de déséquilibre de masse.

11. Procédé selon la revendication 10, dans lequel l'opération de calcul consiste à appeler les données d'étalonnage provenant des relations calculés qui correspondent à la position axiale de l'arbre des plans de correction de déséquilibre de masse.

12. Procédé selon la revendication 11, dans lequel les données d'étalonnage sont obtenues

dans deux plans d'étalonnage et les relati ns calculées sont supposées être linaires.

13. Procédé selon la revendication 10 associé avec les opérations de mise en rotation d l'arbre dans aucune charge montée sur lui, de mémorisation des données de capteurs sans charge et de correction des données mémorisées avec les données n l'absence de charge.



Z
W1
W2
F_{c1}
F_{c2}
Z_1
Z_2
e
P1
P2
c
d
Z5
Z_4
b
19
Z_3
a
12
F_R
F_L
Z_0
18
17
13
11
14
16

FIG_1

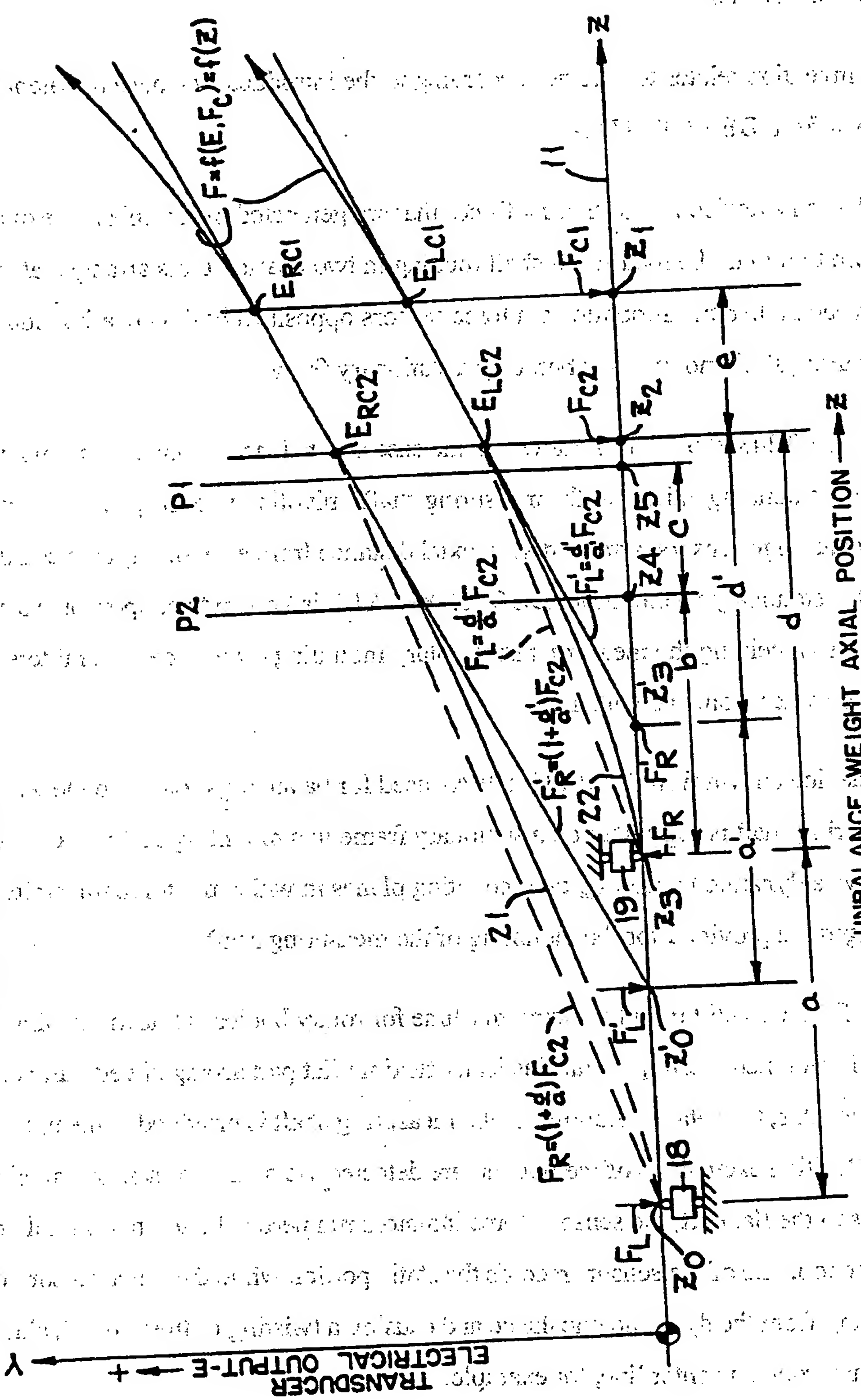

F=f(E,F_C)=f(Z)
UNBALANCE WEIGHT AXIAL POSITION → Z
TRANSDUCER ELECTRICAL OUTPUT-E + → Y
P1
P2
18
19

FIG-2